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Noise: Effects and Control*

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INTRODUCTION

Noise, defined as unwanted sound, has become one of the important problems associated with man and his work and play. Noise and its attendant problems are not new; what is new is the intensity (loudness) which the noises now often attain and the large numbers of people who are exposed [11, 14]. This has greatly increased the incidence of injury due to noise. Clinical, laboratory and field investigations, however, have provided much useful information as to the etiology and

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effects of exposure to high-intensity noise. This knowledge has made possible the development of procedures which can minimize or eliminate adverse effects.

SOUND

Sound is produced by the vibration of objects such as reeds, strings, and membranes or of air, in which turbulence is created by the shearing effects of hot and cold gas mixtures, and is transmitted through gaseous, fluid and solid media.

The magnitude of sound is usually measured in terms of sound pressure (microbars or dynes per square centimetre) and the range of sound pressures of sounds or noises to which man is exposed is very large (see Table I).

TABLE I

Sound Pressure Levels of Various Sounds

Sound Pressure Level (decibels)	Sound Pressure (microbar)	Sound Generation Source	Point of Measurement
140	2000.0	50 HP Victory Siren	100 feet
	1000.0		from source
130			
120	200.0		
	100.0		
110		Submarine Engine Room	Ambient
		S-55 Helicopter	Pilot position
100	20.0	Viscount Aircraft	Pilot position
	10.0	Neptune Aircraft	Pilot position
90		Subway Car	Inside
		Comet III Aircraft	Pilot position
80	2.0	Busy Street	Ambient
	1.0	Noisy Restaurant	Ambient
70		Conversational Speech	3 feet
		Average Office	Ambient
60	0.2		
	0.1	Private Office	Ambient
50			
40	0.02	Average Home (Children	Ambient
	0.01	Asleep)	
		Broadcast Studio	Ambient
30			
20	0.002		
	0.001		
10			
0	0.0002		

For example, from silence to painful sound is an increase in sound pressure of from 0.0002 to about 1000 microbars. In order to deal with this broad range of pressures, a logarithmic system has been adopted. In this system, where logarithms are taken to the base 10, the unit of sound magnitude is known as the bel and is the logarithmic ratio of two sound pressures. To avoid inconvenient fractional values, and because the bel is a large unit, the decibel (dB), one-tenth of a bel, is used. The sound pressure level (SPL) in dB, corresponding to the sound pressure p, in microbars, is

$$\text{SPL (dB)} = 20 \log \frac{p}{p_1}$$

where p_1 is the reference sound pressure. All dB levels referred to in this paper have a reference pressure of 0.0002 microbar. One microbar of sound pressure corresponds to a SPL of 74 dB while a sound pressure of two microbars corresponds to 80 dB, i.e., doubling the pressure increases the SPL by 6 dB. Changing the sound pressure by a factor of 10 changes the SPL by 20 dB.

The SPL or intensity of the sounds with which we are most familiar vary from 50 to 115 dB. There are, of course, some sounds whose levels are below 50 dB and some noises whose SPL exceed 115 dB. For example, the ambient noise level in a broadcasting studio may be as low as 25 dB while the level of noise generated by a large jet engine may be as high as 160 dB.

The sound energy distribution of sounds or noises varies considerably [7, 9]. As shown in Table II, certain types of furnaces and

TABLE II

Spectra, Various Industrial Noises
(Mean SPL within octave bands is given in dB)

Source	Octave Bands (cps) 37.5–75	75–150	150–300	300–600	600–1200	1200–2400	2400–4800
Furnaces	100	99	98	98	94	88	86
Mixers	98	93	90	89	[illegible]	85	82
Welding Equipment	88	86	87	90	[illegible]	101	103
Lathes	90	86	85	88	91	100	97
Drills	85	86	90	94	95	93	90
Saws	90	91	94	99	101	103	102
Riveting and Chipping	125	124	124	125	127	125	125
Tools with Steam or Air Hiss	88	90	92	96	97	98	101
Planers	87	98	102	104	105	107	103

(Karplus and Bonvallet, 1953)

mixers have their main sound energy in the low frequencies, i.e., <1000 cycles per second (cps). Drills, riveting and planing devices usually generate noise whose sound energy is spread almost equally over all frequencies from 100 to 10,000 cps. Some saws, steam or air tools have their significant sound energy mainly in high frequencies, i.e., >1000 cps. A freight train generates noise whose main energy is in the low frequencies, i.e., between 37.5 and 150 cps, as indicated in Table III. A vacuum cleaner generates noise whose highest energy is in the

TABLE III

Spectra, Various Noises
(Mean SPL within octave bands and overall is given in dB)

Source	Over-all SPL	Octave Bands (cps) 37.5–75	75–150	150–300	300–600	600–1200	1200–2400	2400–4800	4800–9600
Highway Noise (Shoulder of Road)	85	78	80	80	82	75	72	67	56
Freight Train (100')	102	90	92	84	81	74	72	70	72
Power Mower	73	52	55	65	62	60	58	56	48
Vacuum Cleaner	80	52	60	65	70	75	69	71	67
Car (Front Seat, 50 mph)	88	83	84	73	64	42	39	33	25
Subway (20')	96	—	88	90	89	85	80	71	62
CF-100 Aircraft (Idling Speed)	108	—	86	85	91	98	102	104	100
Comet 1A Aircraft (Idling Speed)	116	88	87	82	95	115	103	94	89

mid and upper frequencies, i.e., 300-4800 cps. Jet engines produce, particularly at idling speeds, noise whose main sound energy is in the upper frequencies, i.e., >1000 cps [4, 12].

HEARING

(1) Effects of Noise on Hearing Sensitivity and Acuity

Young people, with normal hearing, may hear all tones (frequencies) from 20 to 20,000 cps. As indicated in Figure 1; individuals do not hear them equally well at very low SPL [3]. At an SPL of 100 dB, however, they may hear each tone equally well, i.e., the perceived loudness of all frequencies is the same for the same sound pressure.

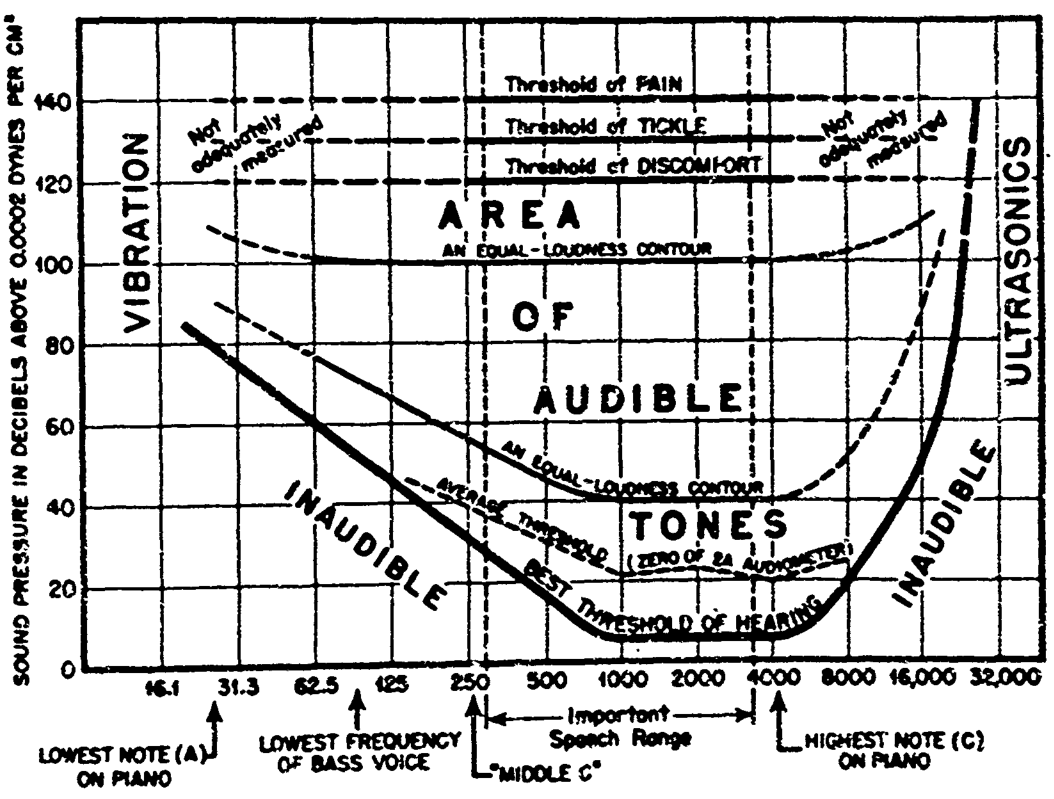
There is considerable evidence, both clinical and experimental, to indicate that exposure over a period of years to high-intensity noise whose overall SPL exceeds 85 dB may cause permanent hearing loss.

Some individuals who are highly susceptible to noise, however, may sustain permanent hearing losses with less exposure to lower levels of noise. There are, unfortunately, few data to indicate the proportion of these people in the general population and as yet no accurate and simple tests are available by which they can be identified.

The threshold of pain, which occurs for most individuals at a level of approximately 130 to 140 dB, has been used in some instances as an index of whether a noise was harmful or not. Unfortunately, for the exposed individual, this level is approximately 45 to 55 dB higher than the level at which damage to the hearing mechanism may be produced by long-term exposure to noise. It should be noted that many individuals develop hearing losses as a result of aging, as shown in Figure 2 [6]. In addition, disease or other pathological factors which are not related to exposure to noise may result in deafness. It is most difficult to distinguish between hearing losses due to non-noise factors and those occasioned by exposure to noise.

FIGURE 1

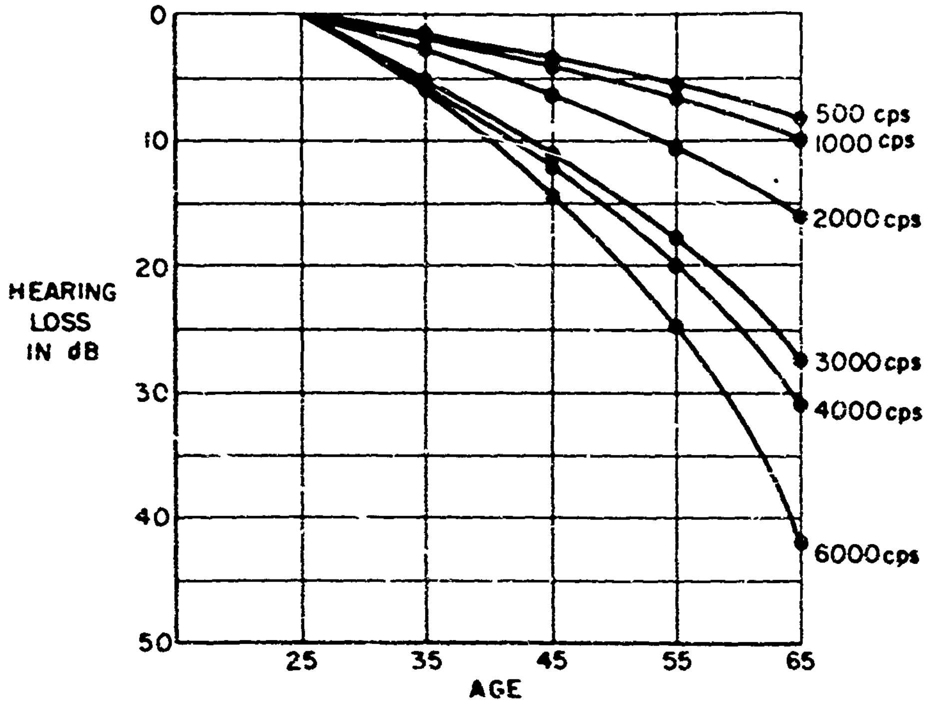
AREA OF AUDIBLE TONES



(DAVIS, 1947)

FIGURE 2

CURVES OF PRESBYCUSIS PLUS SOCIOCUSIS
FOR MALE OFFICE WORKERS
1954 WISCONSIN STATE FAIR HEARING SURVEY (GLORIG 1958)

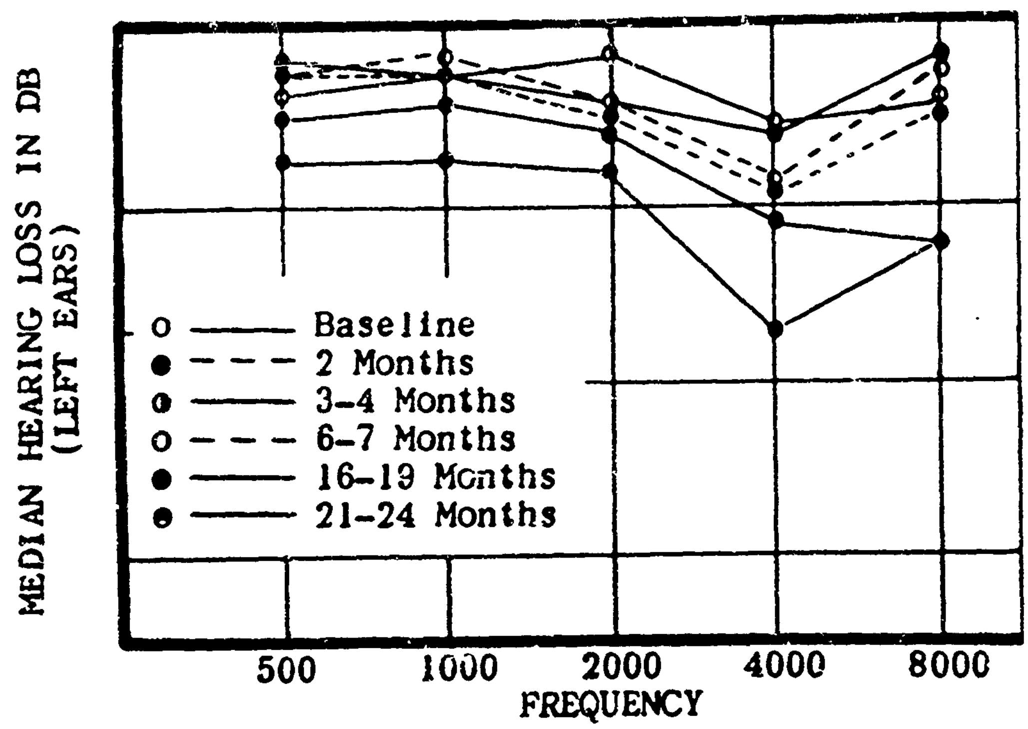


Losses of both hearing sensitivity and hearing acuity resulting from hazardous exposure to high-intensity continuous-type noise, and as indicated in Figure 3, are normally characterized first by a decrease in sensitivity in the neighborhood of 4000 cps [1, 19]. The pathology usually involves the inner ear, with damage to the hair cells of the organ of Corti, and is frequently accompanied by tinnitus (head noises) and possibly by recruitment (abnormal growth in loudness perception). The development of such hearing loss is usually so gradual and in fact so insidious that the individual is usually unaware of his condition until it has become serious. Unfortunately, deafness of this type, called nerve or perceptive deafness, is not reversible. Exposure to short bursts of noise, e.g., gunfire, may in the beginning, cause conductive losses, i.e., hearing losses through a wide range of frequencies, particularly at the low frequency end. This type of loss is due to damage to the conductive mechanism of the ear and may in some cases be reduced through the use of surgery or other therapy. Continued exposure to this type of noise will result in damage to the inner ear and permanent deafness.

Studies made of the effect on hearing sensitivity of workers in industrial environments, exposed to high-intensity noise, indicate that whether deafness is sustained or not depends upon the regular use and effectiveness of the hearing protection devices provided. The type and degree of deafness sustained when hearing protection is not worn depends on the SPL and spectra of the noise as well as the exposure time(s) and the susceptibility of the individual to noise. Individuals exposed to noise whose level exceeds 85 dB need an effective hearing

FIGURE 3

PROGRESSION OF HEARING LOSS IN PERSONS WORKING IN NOISE (GLORIG 1958)



conservation program. The effects of various degrees of deafness on the perception of speech is indicated in Figure 4 [25].

(2) Hearing Conservation

Hearing losses due to exposure to high-intensity noise whose overall level does not exceed 150 dB can, in most instances, be prevented by using adequate hearing conservation procedures.

Several years ago the Defence Research Medical Laboratories (DRML) of the Defence Research Board of Canada were asked to develop a hearing conservation program for the Canadian Armed Forces. A program, outlined in Table IV, was developed which included the designation of hazardous exposure areas, hearing protection criteria, sound abatement procedures, hearing testing (enlistment, monitoring and discharge), use of efficient hearing protection devices, an education program and a periodic review of results [15].

TABLE IV

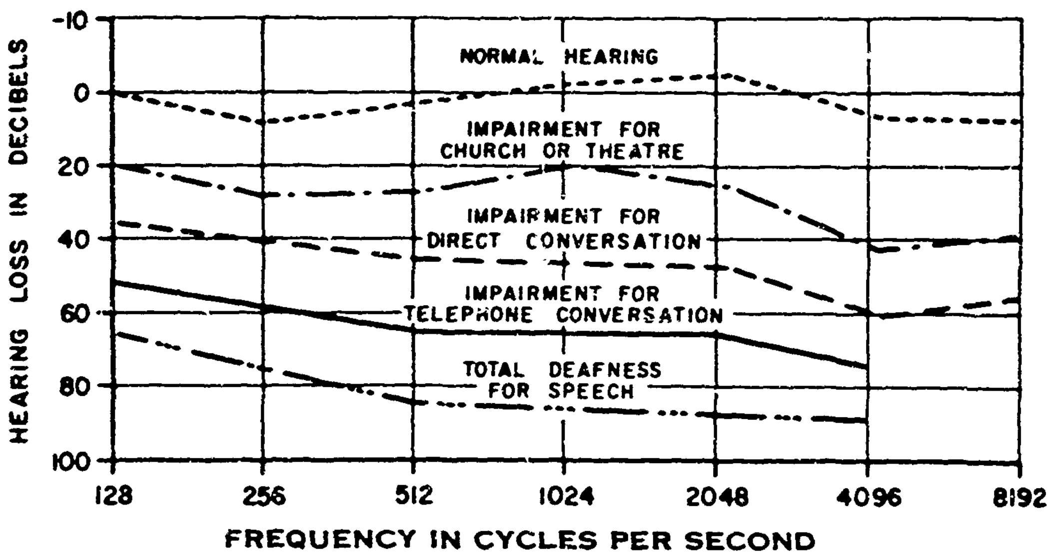
A Hearing Conservation Program

1. Criteria for conservation of hearing
2. Designation of hazardous areas
3. Sound abatement
4. Hearing testing
5. Protection equipment and procedures
6. Education
7. Data collection and processing

FIGURE 4

EFFECT ON VOICE COMMUNICATION OF VARIOUS DEGREES OF HEARING LOSS

(AFTER WOODSON, 1954)



Areas with potentially hazardous noise, in which normal voice communication is impaired, should be surveyed by trained personnel

using calibrated equipment and should include both overall level and octave-band measurements [13]. Information should be obtained as to the number and length of the hazardous exposures by the individuals working in the area. Such information will permit prediction of maximum permissible exposure times. Once the environment of a particular noise generator has been designated as hazardous, periodic noise surveys should be made to indicate any change in this status or the requirement for changes in hearing conservation or sound abatement procedures. Modification of the noise generator or changes in operating procedures should always be accompanied by a measurement of the noise levels and spectra.

Criteria for the conservation of hearing should ensure protection for most individuals, and permit effective conservation measures in a majority of situations, with no need for the continual collection of large amounts of data and complex calculations. Several criteria have been developed [5, 15, 22]. They differ somewhat in the minimum noise level at which hearing protection is required, in the complexity of noise analyses and in the training required for supervisory personnel. These differences are, in part, due to differences in the degree of protection specified and in the duration of the exposure for which protection is required. The criteria developed at DRML and used by the Canadian Armed Forces are shown in Table V. If these criteria are properly applied they will

TABLE V

Criteria for Protection of Hearing During Exposure to High-Intensity Noise

SPL (dB re: 0.0002 microbar)	Exposure Time	Type of Protection Required
85 - 100	4 hours per day	Ear Plugs **or** Earmuffs
100 - 130	any	Ear Plugs **or** Earmuffs
130 - 150	any	Ear Plugs **and** Earmuffs
150 -	any	Whole Body Protection

ensure adequate hearing protection for most individuals exposed to high-intensity noises whose levels are below 150 dB.

The sound abatement procedures, depending upon the sources and nature of the noise environment, may include modification of the noise sources, running of the noise-generators at reduced power, isolation of such generators with sound-attenuating structures, and reduction of the number and duration of generator operations.

The testing of hearing is an integral part of a hearing conservation program. The hearing tests should be administered at the beginning of employment, periodically during employment, and at the termination of employment. They must be conducted by **qualified personnel** with calibrated instruments in a proper sound environment. Both automatic and manual types of audiometers are suitable for routine and screening tests; manually-operated audiometers only are satisfactory for clinical evaluations.

Accurate audiograms may be obtained only when at least 48 hours has elapsed since the individual's last exposure to high-intensity noise. A complete air-conduction hearing test should be administered as part of the medical examination at the time of employment and retirement. In order to ensure the effectiveness of the hearing conservation procedures, hearing tests, using frequencies of 2000 and 4000 cps, should be given at intervals of six months to all personnel routinely exposed to high-intensity noise. For individuals exposed to continuous-type noise, hearing losses at these frequencies are indicative of losses at the other speech frequencies also. Changes of 10 dB or more in hearing sensitivity require the administration of three complete air-conduction hearing tests on three different days during a period in which the individual is not exposed to high-intensity sound.

Hearing protectors consisting of earmuffs, ear plugs or helmets are effective only when fitted and worn properly [23]. Training and patience will overcome any initial difficulties experienced in the perception of auditory stimuli under noisy conditions. In environments where the level of noise is between 85 and 120 dB the perception of speech and other ambient sounds will be improved by the wearing of hearing protectors, while in quiet environments the loosening or removal of the hearing protecting device may be desirable for satisfactory voice communication. The sound attenuation characteristics of hearing protectors

TABLE VI

Sound Attenuation (decibels) of Various Ear Protector Devices

Device	Frequencies (cps) 125	250	500	1000	2000	3000	4000	6000	8000
NRC Type Earmuff	25	27	39	40	41	44	45	36	32
NRC Type Earmuff in Nylon Helmet	23	26	31	39	36	44	46	35	33
V-51R Type Ear Plug	15	14	16	19	28	28	23	25	31

used by the Canadian Armed Forces are shown in Table VI. The V-51R type ear plug was developed at the Phsycho-Acoustic Laboratory, Harvard University, by Drs. W. A. Shaw and P. S. Vencklasen, while the NRC type earmuff was developed at the National Research Council, Ottawa, Canada, by Drs. E. A. G. Shaw and G. J. Thiessen [20, 21]. Both of these devices may be worn for many hours without discomfort.

The success of any hearing conservation program will depend on the practicability of the procedures, the enthusiasm of the supervisors, the information given to the personnel involved and the degree of cooperation among the various members of the hearing conservation team (employee, physicians, audiologists, and administrators) [17]. Management, as well as individuals who are exposed to high-intensity sound, should be aware of the risks accompanying such exposures and of the simple procedures and protective equipment by which these risks can be effectively minimized.

VOICE COMMUNICATIONS

(1) Effects of Noise on Speech

Communication systems basically consist of a source, a transmitter, a channel, a receiver, and a destination (see Table VII). In the

TABLE VII

Voice Communication System

1.	Speaker
2.	Speaker's Sound Environment
3.	Speech
4.	Microphone Mounting
5.	Amplifier
6.	Radio Link
7.	Earphones
8.	Earphone Mounting
9.	Listener's Sound Environment
10.	Listener

evaluation of the effectiveness of such a system one must consider the intelligibility of the speaker, his acoustical environment, the basic intelligibility of the message, the characteristics of the microphone, amplifier, radio transmitter, receiver and earphones, as well as the hearing sensitivity and acuity of the listener and his acoustical environment. Adequate perception, particularly in noise, of speech requires the generation

and transmission without distortion of frequencies from 300 to 6000 cps. The vowels in speech contain mainly low-frequency energy, while the consonants contain more high-frequency energy. While the vowels contain the highest sound energy it is the consonants that contribute the most to the intelligibility and the perception of speech.

The noise present in many work environments contains mainly low-frequency sound energy. Since sounds are masked most effectively by similar and higher frequencies (1 to 2 octaves above) low-frequency noise does not usually mask or disrupt speech reception as seriously as wide-band noise. Since the frequencies important for producing intelligible speech lie between 300 and 6000 cps, a noise whose spectrum is correspondingly wide has the maximum masking effect.

One method of evaluating the masking effect of a noise on voice communication depends upon the use of Speech Interference Levels (SIL) [2]. The SIL is defined as the average SPL, in dB, in the octave-bands 600-1200, 1200-2400 and 2400-4800 cps. The SIL should be used only under certain conditions, i.e., when the noise has a gradual slope in spectrum, or when no intense low-frequency sound energy is present. Maximum SIL permissible for speech communication under various conditions are shown in Table VIII.

TABLE VIII

Criteria for Control of Background Noise in Various Spaces

Type of Room	Maximum Permissible SIL (Measured when room is not in use)
Small private office	40
Conference room for 20	30
Conference room for 50	25
Movie theater	30
Theaters for drama (500 seats, no amplification)	25
Coliseum for sports only (amplification)	50
Concert halls (no amplification)	20
Secretarial offices (typing)	55
Homes (sleeping areas)	25
Assembly halls (no amplification)	25
School rooms	25

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While the masking effectiveness of noise is related to its SPL, spectrum, temporal continuity and annoyance value the most important

of these is its SPL. If the SPL of the noise is greater than the SPL of the speech, i.e., a negative signal-to-noise ratio, other aspects of interference become irrelevant. This ratio is numerically equal to the difference in dB between the level of the signal and the level of the masking noise. Changes in the signal-to-noise ratio affect the intelligibility of speech, i.e., as the signal-to-noise ratio becomes more positive (speech level higher than noise level) the intelligibility of the speech increases. Nevertheless, some sounds (digits, strong vowels, etc.) can be detected at a signal-to-noise ratio of —18 dB with masking white noise [11]. For satisfactory voice communication the speech level should exceed the noise level by at least 15 dB. Since English speech is structurally redundant, as little as 70 per cent intelligibility is found acceptable for most speech situations. If standardized procedures and phraseologies are used, unintelligible words can often be inferred by the listener from the context or conditions.

The masking efficiency of noise on speech is also related to its annoyance value. In general, the annoyance value of a noise increases as the signal-to-noise ratio becomes more negative and as the loudness and pitch of the noise is raised or changed irregularly. Noise having such characteristics will usually not prevent a determined listener from receiving a message, but from the point of view of listener efficiency such noises should be avoided wherever possible.

(2) Effective Voice Communication

The greatest gain in voice communication efficiency can be obtained through the more intelligent use of people. No communication system is better than the personnel who use it. Maximum efficiency in voice communications can be obtained by (i) the proper selection and training of speakers and listeners, (ii) the use of intelligible words and phrases in verbal messages, (iii) the use of standardized messages, (iv) the use of standardized radiotelephony procedures, (v) the use of proper communication equipment and (vi) the adequate maintenance and tuning of the audio equipment [16].

WORK EFFICIENCY

(1) Effects of Noise on Skilled and Unskilled Tasks

It has been very difficult to determine accurately the effects of various types of noises on the effectiveness which man can carry out skilled and unskilled tasks [8, 10, 18, 24]. Field studies often suffer from lack of control of various factors possibly affecting the field conditions, while laboratory studies may suffer from a lack of realism.

In evaluating the effects of noise on work behaviour one must take into consideration such influences as motivation, work environment, employee-employer relationships, etc. There have been suggestions that music, introduced at the same levels as the noise, results in an increase in work efficiency. There is some doubt, however, as to whether this increase is a result of an attitude change, i.e., management is trying to provide good working conditions, or the result of the acoustical stimulus.

Unusual noises may produce a decrease in work efficiency. There are few data, however, to indicate whether their effect is greater on practiced or unpracticed tasks. Since any effects of noise on human performance are related to its distracting value the tasks most susceptible are those involving sustained attention over long periods of time, complex rather than simple, and paced (by the system).

Generally speaking, noises whose level is below 85 dB do not appear to affect work behaviour significantly, although noises of these levels may, of course, interfere with the efficiency of voice communications.

Noise, by definition, is any unwanted sound. Since this is a subjective definition the classification of a sound as a noise or not is dependent upon many factors. For example, music heard in the afternoon may be pleasant and enjoyable. The same piece of music heard at 2 a.m., however, may be unpleasant or disturbing, i.e., unwanted, and therefore, is then **noise**. Likewise, the sounds produced by your own children may be pleasant to you but are classified as noise by your neighbours. Your neighbour's lawn mower may produce nothing but noise for you, whereas the sound from your own power mower indicates that it is doing an effective job of cutting your grass.

(2) Reduction of Noise Effects

The use of sound abatement procedures and equipment, i.e., sound attenuation and absorbent structures, isolation of noise generating equipment, reduction of noise generator running time, use of effective hearing protection devices and procedures, and proper voice communication equipment and procedures, will reduce the effective SPL and in some instances change the spectra of noise. Suitable noise levels for various work areas are shown in Table IX [18].

There appears to be little evidence as to the relation between noise and the number of industrial accidents. Noises, which by their intensity or unfamiliarity may cause a "startle" reaction, may be poten-

TABLE IX

Recommended Acceptable Average Noise Levels in Unoccupied Rooms

Type of Space	Sound Level, Decibels ("A" scale)
Radio, recording and television studios	25-30
Music rooms	30-35
Legitimate theaters	30-35
Hospitals	35-40
Motion picture theaters, auditoriums	35-40
Churches	35-40
Apartments, hotels, homes	35-45
Classrooms, lecture rooms	35-40
Conference rooms, small offices	40-45
Court rooms	40-45
Private offices	40-45
Libraries	40-45
Large public offices, banks, stores, etc.	45-55
Restaurants	50-55

WADC TR 52-204

tially dangerous. Auditory warning signals may be masked by high-intensity noise. Such considerations must be noted in the development and application of safety measures. The degree of annoyance or irritation suffered through exposure to noise depends upon the nature of the work and the nature of the noise. More specifically, the annoyance will be related to the interpretation and distraction value of the noise. Annoyance usually increases with greater loudness and higher pitch of the noise.

SUMMARY

The type and degree of the effects on man of exposure to high-intensity noise is determined primarily by (i) the type of noise, i.e., continuous or interrupted, (ii) the spectrum of the noise, i.e., low or high pitch, (iii) intensity (loudness), (iv) length of exposure(s), (v) the acoustic environment, (vi) previous noise exposure(s), and (vii) the state of the individual's hearing mechanism.

The main effects of exposure to high-intensity noise are (i) deafness, temporary and permanent, (ii) interference with voice communication, and (iii) changes in the efficiency with which man can do skilled and unskilled tasks. These effects may be accompanied by the arousal of feelings of fear, apprehension, annoyance, or dissatisfaction.

The effects produced by exposure to noise can be eliminated or reduced significantly by the use of (i) adequate hearing conservation procedures, (ii) proper voice communication phraseologies, procedures and equipment, and (iii) effective noise attenuation and abatement procedures and equipment.

With the knowledge, procedures and equipment available today, there is no need for most individuals exposed to high-intensity noise (85 to 150 dB) to suffer permanent deafness. Similarly the use of proper communication equipment will permit adequate voice communication in areas where the level of noise may be as high as 130 dB, The use of adequate noise abatement procedures and equipment will reduce the antagonistic responses to noise arising from the irritation and annoyance aroused in many instances by exposure to high-intensity noise.

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QUESTIONS AND ANSWERS

Q: Is it normal reaction for a person to be staggered momentarily by a loud, sharp sound such as a whistle? What takes place in the mechanism of hearing?

A: Exposure to very sharp, high-intensity noise **may** cause such a response. A pressure or sound wave generated by a gun, in terms of time and amplitude, has a very steep front — it's very sharp, in other words. Such a wave, if large enough, causes the eardrum to be pushed in further than is normal. The eardrum normally vibrates in response to changes in sound pressure in the external ear canal. The eardrum is connected, by a series of three bones called ossicles, to a very thin membrane called the oval window through which the vibrations from the eardrum are applied to the liquid which fills the inner-ear cavity. The inner ear contains the cochlea which is the sense organ of hearing and includes the basilar membrane which contains many thousands of hair cells. The sensation of hearing follows the excitation of these hair cells by the movement of the liquid. The inner ear also contains the organs of balance. The eardrum may be vibrated so strongly that large-amplitude vibrations are set up in the liquid in the inner ear which not only stimulates the basilar membrane, but at the same time

disturbs the action of the semi-circular canals which control the person's balance. This could result in a momentary loss of balance.

Q: What effect does a combination of noises, such as electric furnaces and vibrators have on the nervous system and on hearing?

A: Without adequate information as to the type of noise generated I can't answer your specific question. But certainly any vibration, whether airborne or applied directly to the head, will set up vibrations in the external ear canal, the middle ear and may also cause vibrations in the liquid in the inner ear. If the intensity of the vibrations are great enough, long-time stimulation could cause damage to hearing.

Q: Will it affect your nerves though?

A: If the overall level of the noise is less than 150 decibels it should affect your "nerves" about in the same way as any other unpleasant sensation would.

Q: If a man loses his hearing then, would he be able to claim compensation?

CHAIRMAN WEISBACH: As you know, we still have the problem with the Compensation Board concerning industrial deafness; and I believe I mentioned this morning we are again dealing with the Board on this specific matter. The Ontario Compensation Board at the present time has a ruling that you will be compensated for a loss of hearing if you have a loss of more than 25 decibels and if you are removed from the source of noise; otherwise you will not be compensated.

Q: When a physician examines the ear, he usually does so by visual means, while the various hearing aid companies use a machine which purportedly gives an accurate measure of hearing loss. My question is, is there more merit in having a doctor make a visual examination or to have mechanical means to make a proper and correct determination of the hearing loss?

A: In the visual examination that you refer to, the doctor is determining the conditions and action of the eardrum, and to a certain degree the mechanism or the action of small bones (ossicles) in the middle ear. It's becoming more and more prevalent for both a visual and a pure-tone audiometry examination, the kind you've referred to, to be made. The audiometer is a device that generates pure tones and the patient indicates the levels at which he can

hear them. The device is calibrated so that one can determine the relationship between the patient's hearing level with that of "normal" hearing individuals. Hearing examinations must be carried out in sound environments where the noise will not mask any of the tones being generated by the audiometer. If the noise is loud enough to cause masking, then this will show up as a hearing loss. Pure-tone audometry, as it is called, gives an indication of the person's threshold of sensitivity or perception to pure tones. For many types of deafness, pure-tone thresholds are not related to the person's perception of speech. What one hears at a threshold level may be different from what he hears at levels of 15, 20, 40 or 50 decibels above the person's threshold. The most adequate way to determine the efficiency with which deafened individuals perceive speech is by using speech as the test material. In many instances, however, all the required information is not obtained by testing with speech in a quiet environment. One seldom hears speech in a quiet environment. The most adequate way to determine a deafened individual's ability to perceive speech is to test his perception of the speech under various noise conditions. Even with this type of testing one must be very careful in interpreting the results. It would be useless to use recorded speech containing unfamiliar words spoken with a dialect with which the deafened individual has had no experience. In this instance you're not measuring his deafness but his familiarity with the test words and the speaker's dialect. Testing an individual's efficiency in speech perception is a difficult task.

Q: In our nickel industry in Sudbury, we find quite often that miners are very hard of hearing. Is the reason the depth these miners are working at, the excessive vibrations from the drills, or the heavy noise from the drillings and blastings, or a combination of all three? Could these things affect their hearing?

A: Unfortunately I don't know the noise levels and spectra to which they're exposed. There should be no damage to the hearing mechanism due to the pressure changes, if the person, in changing depths equalizes the air pressure between the external ear canal and the middle ear. If the noise levels are high, i.e., above 85 decibels, and if the person does not wear hearing protectors and is exposed for long periods of time, i.e., years, then deafness could result from such exposures.

Q: What about the vibrations from the drilling — hand vibrations coming through the body?

A: Again, without having measured the types of vibrations that you refer to, I would suggest that the damage to the hearing mechanism would be by the airborne vibrations (noise).

Q: At our plant we have a large shearing shed with shears going eight hours a shift, three shifts a day. In your opinion what would be the best type of ear protection for these men?

A: Again, I have not measured this type of noise, but the most effective earmuffs provide more protection from noise to the hearing mechanism than do the most effective ear plugs.

Q: Somebody once spoke to us and he talked about the anvil of the ear; this is something I'm not familiar with.

A: The "anvil" refers to the incus, one of the small ossicle bones which lie in the middle ear.

Q: In our particular plant, we have 34 mills in operation, and I think this would possibly be classed at 150 decibels that you mentioned in your illustrations. We have employees in our plant that land up in the hospital and the doctors don't know what's the matter with them. In all the cases I've gotten information on, the doctors all claim this is a nervous stomach. You've probably had some experience in this — could this be caused through the hearing, because it's so noisy you can't hear yourself talking there?

A: I have not measured the noise to which you have referred. However, vibrations being carried up through the man's arms and legs, should have less effect than the air-borne sound on a person's hearing mechanism. As an example, if you introduce a vibration (pure tone) at the head and measure its intensity at the abdomen, there would be a difference of approximately 60 decibels; so that a sound of 140 decibels impinging on your fingertips, should be reduced by at least 50 decibels by the time it reaches the ear. I would suggest that in this instance any damage (deafness) that there is would be caused by the air-conducted vibrations not those through the body.

Q: I wonder if you'd care to comment a little more on the relationship of noise to fatigue; I'm thinking particularly in relation to air crew, where fatigue and safety are synonymous. And I'd also ask you to comment a little more on the effects of ultrasonic sound.

A: I should like to answer the second part first, if I may, since it will take a very short time. We have measured the noise, generated by turbine engines, and have found that there is significant sound

energy, 115 to 118 decibels, at about 50,000 cycles. Now we know that many thousands of ground crew and air crew have been exposed to this type of noise. There is no documented evidence that this type of noise -- ultrasonic noise — that you refer to, has caused any damage other than to the hearing mechanism. In answer to your first question fatigue and safety are not synonymous, as fatigue increases, safety will in most instances decrease. The effect of noise on the person's work behaviour, has not been adequately investigated. There is no documented evidence available to show that if the air crew is sufficiently rested and wearing adequate sound-attenuating earphones that exposure to aircraft noise inside the cockpit will cause any significant change in their behaviour and more specifically there is no evidence that any changes that have occurred have affected the safety of aircraft operations.

Q: Is there any medical evidence to indicate that because of wearing earmuffs for long periods internal ear injury could take place, due to pressure or lack of exposure to air?

A: Our experience has indicated that the wearing of properly-fitted earmuffs for long periods of time, i.e., four to eight hours per day, does **not** cause injury to the ear. The commercially-available earmuffs examined by us should not, if properly fitted, cause increases in the air pressure in the external ear canal. Lack of exposure to the ambient air for several hours each day should not affect a "normal" external ear canal or eardrum.

Q: Has your Department ever made a noise intensity test of a wood working department having cut-off saws, rip saws, band saws, shapers, etc.?

A: The Defence Research Medical Laboratories have not made surveys of noise generated by woodworking equipment. I would suggest that, for information regarding such noise levels and spectra, you contact Dr. G. J. Thiessen, Acoustic Section, National Research Council, Montreal Road, Ottawa, Canada.

Q: The table of "Criteria for Protection" shows that noise over 150 DB requires whole body protection: does lack of the whole body protection affect hearing or other organs as well?

A: The evidence available regarding exposure by individuals to noise whose overall level exceeds 150 decibels indicates that the body may be under severe stress. Such exposures, over a period of time, could result in damage other than hearing to the individual. Individuals should avoid, if at all possible, such exposures.

Q: Is there any official body that will enforce use of protective measures in the factories and industrial establishments?

A: The Ontario Department of Health and the Workmen's Compensation Board should be contacted concerning the enforcement of protective measures as regards noise exposure.

Q. Is there such a complaint as a perforated eardrum, and if so, is this accounted for by noise alone, physical mistreatment alone, or a combination of both?

A: Eardrums may become perforated because of a number of factors, such as external or middle-ear infections, puncturing by foreign objects, intense explosions or by exposure to rapid changes in air pressure where the equalization of the air pressures on both sides of the eardrum cannot be achieved.

Q: Would noise, of any major volume or consistency, prolonged or of short duration, be reduced and become less injurious to the ears if the person or persons exposed to such noises were to open the mouth? Most people have a tendency to do just the opposite.

A: The opening of the mouth should not have any significant effect in reducing hearing losses due to exposure to continuous-type noise.

Q: Does the Province of Ontario have the equipment and men available to take decibel readings and the power to recommend corrective measures where decibel readings of over 100 are found in industry? If so, who should be contacted?

Q: In order to set up a hearing conservation program are sound measuring devices available through provincial or federal government branches, or how could we go about such a program?

A: The Industrial Hygiene Laboratories, Ontario Department of Health, 360 Christie Street, Toronto, should be contacted as to the availability of sound measurement and recording equipment. The Department of Health and Welfare should be contacted as regards equipment available from the Federal Government.

Q: Would the noise of steel rollers, dropping into a steel truck at regular intervals (with a loud bang) injure the hearing canal and what effect would it have on the nervous system?

A: It is impossible to give an adequate answer to your question without having information regarding the overall and spectral levels of the noise you refer to. However, as indicated in my paper, permanent hearing loss may result from years of exposure to noise whose overall level exceeds 85 decibels (re: 0.0002 microbar).